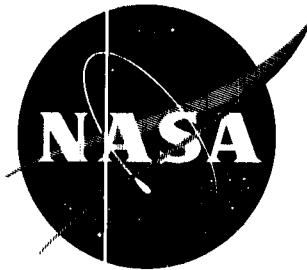


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TECHNICAL NOTE

D-1932

**FREE-FLIGHT INVESTIGATION OF THE DEPLOYMENT,
DYNAMIC STABILITY, AND CONTROL CHARACTERISTICS OF A
1/12-SCALE DYNAMIC RADIO-CONTROLLED MODEL OF A
LARGE BOOSTER AND PARAWING**

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**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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SUMMARY

An investigation has been conducted to determine the deployment, dynamic stability, and control characteristics of a parawing-rocket booster model using a radio-controlled free-flight technique. The parawing utilized folded rigid members. The results show that this deployment technique provides consistent transitions from essentially vertical descent at subsonic speeds with the parawing stowed on the booster to normal trimmed gliding flight with the parawing deployed. For the particular deployment configuration selected, a small drogue parachute was needed to hold the parawing away from the booster during deployment until the parawing was developing lift properly. In general, the flight characteristics of the model were fairly satisfactory for an unmanned vehicle although the model had a small constant-amplitude Dutch roll oscillation and some undesirable characteristics at the stall. The model was controllable by center-of-gravity movement but the response of the model appeared to be sluggish.

INTRODUCTION

The National Aeronautics and Space Administration has made a study to determine the feasibility of recovering large boosters in the Saturn class by means of a parawing. Information on the aerodynamic characteristics of the parawing are contained in references 1 to 5. The recovery system considered would have the parawing stowed on the side of the booster during the launch or boost phase of flight, and at booster engine cutoff, or first-stage separation, a drogue would be deployed to stabilize the booster which is longitudinally and directionally unstable. After the booster is stabilized, the parawing would be deployed at subsonic speeds, the drogue jettisoned, and the booster would glide back to the launch site or to a down-range site if possible. If these landing sites exceed the range capability of the booster-parawing combination, powered flight or an aerial pickup would have to be considered so that a flight or a tow back to the launch site would be possible.

The present investigation was conducted at low subsonic speeds with a free-flying radio-controlled dynamic model to evaluate qualitatively the deployment, dynamic stability, and control characteristics of the booster-parawing combination. The model consisted basically of the booster suspended beneath the parawing by a system of cables. The parawing used in this investigation could be folded longitudinally and laterally for compact stowage on the side of the booster. The model was controlled by shifting the center of gravity fore and aft for pitch control and side to side for roll or lateral control; shifting of the center of gravity was achieved by changing the lengths of the suspension cables. The deployment process of the parawing primarily consisted of allowing the booster with the parawing stowed on it to fall vertically with a large drogue parachute attached at the end of the booster to stabilize it. Then the parawing was deployed by using a second smaller drogue parachute to pull the parawing away from the booster and holding it until it attained a lifting condition; the drogues were subsequently jettisoned.

To keep free-flight tests to a minimum, preliminary deployment tests were conducted on the model in the Langley 20-foot free-spinning tunnel with the model restrained to prevent damage.

DESIGN CONSIDERATIONS

A brief study has been made to consider some factors in the design of a recovery system for a large liquid-fueled rocket booster. The recovery system will use a parawing system folded for compact stowage on the side of the booster. Aerodynamic devices will be used to stabilize the booster and achieve deployment of the parawing. The parawing was considered to be a 1/12-scale dynamic model of a hypothetical parawing but the model was not scaled aeroelastically nor was it designed to any specific structural standards. The full-scale booster simulated was based on preliminary information obtained on a proposed large booster. This booster was about 71.8 feet long, 21.5 feet in diameter, and the total recovered weight (booster and recovery system) was considered to be about 120,000 pounds of which the recovery system was considered to be about 24,000 pounds. Full-scale moments of inertia of the proposed booster were not available and they were arbitrarily assumed to be similar to values scaled up from those of the 1/12-scale model of the booster.

Parawing

The size of the parawing was determined by several factors. First, a full-scale wing loading between 12 to 18 pounds per square foot was selected so that the glide speed of the booster-parawing combination would be high enough that the full-scale vehicle could easily penetrate against the wind, if necessary, to reach a suitable landing site. It also was desired that the parawing be small enough so that it could be stowed within the length of the booster without folding, if possible, or by folding it longitudinally only once, to simplify the deployment process. On the other hand, it was desired that the wing be large enough so that reasonably low landing speeds could be expected. By considering

these factors, a wing keel length of 100 feet (which could be folded longitudinally once to fit on the booster) and a wing area of 7,070 square feet was obtained for a 45° sweptback flat planform. Based on this wing area and the recovered weight of the vehicle as 120,000 pounds, a full-scale wing loading of about 17.0 pounds per square foot resulted.

A spreader bar was used as a positive means of extending or spreading the parawing laterally and locking it at a deployed sweepback angle of 50° ; this sweepback angle was selected on the basis of results presented in reference 3, which indicated that this angle gave the desired performance. The spreader bar was located as far rearward on the parawing as possible in order to minimize the lateral bending of the parawing leading edges when the parawing was under load, and to require a minimum of tension force (shock cord) to unfold the spreader bar.

Suspension System

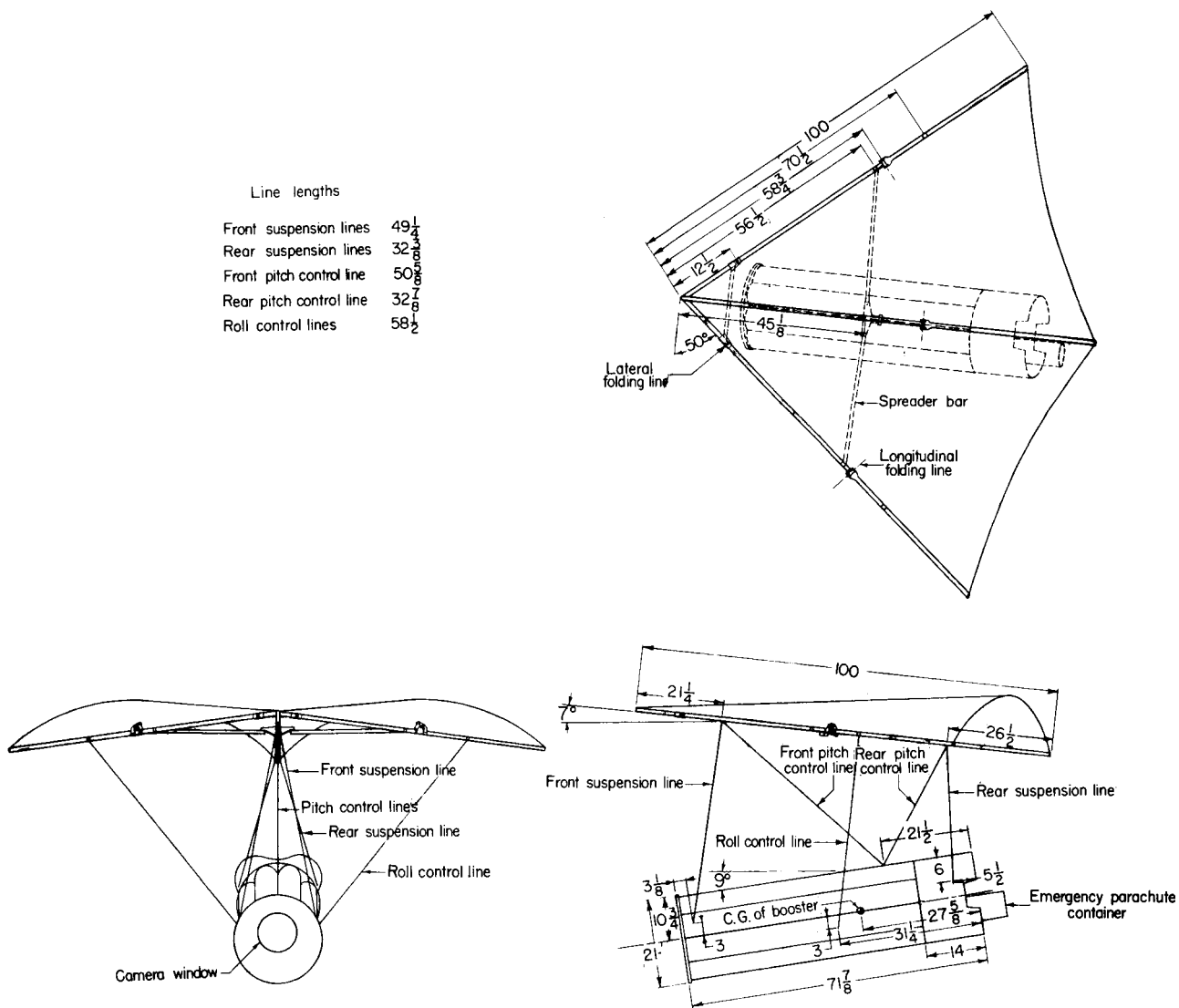
In general, the suspension system attaching the booster to the parawing was designed so that it would provide positive and controllable positioning of the booster relative to the parawing under positive lift. Also the suspension system was designed so that the booster was inclined nose downward to the horizontal an amount that made it approximately parallel to the glide path or relative wind and thus obtain minimum drag. It was assumed the lift-drag ratio would be about four. The booster was located close to the parawing in order to have minimum suspension line length to minimize drag and deployment problems. Observation of glide tests of a small dynamic model of a booster-parawing combination indicated approximately how close they could be before interference effects became too large and/or the longitudinal stability decreased too much.

Front and rear suspension lines were placed on the booster (fig. 1) and were located far apart in order that the parawing could transmit as large as possible stabilizing moments to the booster which, as previously mentioned, was longitudinally and directionally unstable. Attachment points for the pitch-control lines had to be far enough apart so as to prevent slack occurring in either of the lines during gliding or maneuvering flight. The attachment points of the roll-control lines were positioned approximately so that, when a roll-control input was made, there was a minimum of interaction with the pitch control.

Drogue Parachutes

As previously mentioned, a drogue parachute was used to stabilize the model booster before and during the deployment of the parawing. The size of the drogue parachute was determined from preliminary tests conducted on a $1/44.5$ -scale dynamic model of the booster in the Langley 20-foot free-spinning tunnel. During these tests in the tunnel it also was determined that the parawing by itself would not deploy consistently from the side of the booster.

Based on the preliminary results of the small dynamic model tests, considerable thought was given on how to pull the parawing away from the side of the



1/12-scale model of the booster during the deployment process. It was decided to use an additional drogue parachute since it was easy to install and provided relatively large forces for long durations. In order to pull the parawing away from the booster, it was felt that the parachute must apply a nose-up pitching moment to the parawing. To accomplish this, a short mast was attached perpendicular to the top of the parawing and the parachute attached to the end of the mast; initially, the size and location of the mast were somewhat arbitrary.

MODEL CONSTRUCTION AND INSTRUMENTATION

Model

The model booster arbitrarily was ballasted to simulate dynamically a full-scale booster and recovery system at an altitude of approximately 8,000 feet ($\rho = 0.001869$ slug/cu ft) with a gross weight of 120,000 pounds. For this condition, the total weight of the model booster and recovery system was 88 pounds. However, since the model was tested at altitudes of 2,000 feet and 3,500 feet, it was assumed therefore that the model simulated a full-scale booster and recovery system at approximate altitudes of 10,000 feet and 11,500 feet. The center of gravity of the model booster alone was on the axis of symmetry and 27.6 inches from the tail end of the booster. The center-of-gravity positions of the booster-parawing combination presented in this report are given in terms of nondimensional distances measured parallel and perpendicular to the parawing keel. For all but a few of the tests, the center of gravity was located at 54 percent of the keel length back from the nose and 34.9 percent of the keel length below the keel which hereinafter will be referred to as the normal location of the center of gravity. A few tests were also made with a more rearward center of gravity located at 55 percent of the keel length back from the nose and 35.3 percent of the keel length below the keel. The dimensional and mass characteristics of the booster-parawing combination are presented in table I.

TABLE I.- MASS AND DIMENSIONAL CHARACTERISTICS OF MODEL

Mass parameters:

Total weight (booster plus parawing), lb	88.0
Weight of parawing, lb	14.0
Wing loading, lb/sq ft	1.79

Moments of inertia about body axes (booster alone):

I_X , slug-ft ²	1.38
I_Y , slug-ft ²	10.20
I_Z , slug-ft ²	9.71

Parawing dimensions:

Area (flat, 45° leading-edge sweep), sq ft	49.1
Span (flat, 45° leading-edge sweep), ft	11.78
Length of keel and leading-edge members, ft	8.33
Included angle between booster center line and parawing keel, deg . . .	16.0

Parawing.- The parawing membrane used on the model was made of acrylic-coated 1.2-ounce-per-square-yard nylon ripstop fabric. The fabric material was essentially nonporous and very flexible as well as being very light. It was cut to a 45° sweepback modified delta flat planform and attached to three structural members all joined at one end to form the leading edges and the root chord, or keel, of the parawing. The wing keel and leading edges were 8.33 feet in length and were constructed of 1-inch hardened aluminum tubing joined to a nose assembly which consisted of 1-inch steel tubing for strength.

For compact stowage the parawing was folded laterally by having the leading-edge members hinged near the nose so the members could be pivoted and thus could lie alongside the keel. Also the leading-edge members and the keel were hinged about halfway back from the nose so that they could be folded longitudinally. Small coiled steel springs in the pivoted or hinged joints for longitudinally folding were used to unfold the wing initially and small metal clips locked the wing at the joints so as to ensure structural continuity across the hinge lines. A spreader bar was used to spread the wing laterally and lock it at a sweepback angle of 50° . The spreader bar was fastened at a point on each leading edge by a hinged joint. The center portion of the spreader bar was hinged to a plastic block which could slide longitudinally along the keel. A shock cord was attached between the block and the aft end of the keel to force the spreader bar to unfold and thus spread the wing laterally to its design sweepback. Cables which could be released in sequence by radio command were used to hold the parawing securely to the booster in its stowed condition and yet permit it to unfold longitudinally and then extend laterally.

Booster.- The 1/12-scale model of the booster was constructed of molded fiber-glass-reinforced plastic. A few preliminary tests utilized a simplified model of aluminum; aluminum sheet metal was wrapped around a framework and thus formed a smooth cylinder. The model was equipped with electric-motor actuators which operated control arms which were rotated from the neutral positions in either direction to a preset position with a flicker or bang-bang action in response to radio control signals and back to neutral with cessation of the signals. The suspension lines from the wing keel (used for pitch control) and from leading edges (used for roll control) were attached directly to the control arms. Movement of the arms caused the fuselage to move relative to the wing and thus the lift vector was displaced with respect to the center of gravity to achieve longitudinal and lateral control. The suspension lines consisted of 1/16-inch-diameter steel cables. It should be noted that the flicker or "on-off" type of control action was designed to move the control arms to their full deflection at a rate of about 100 degrees per second under a no-load condition. However, under actual flight conditions the rate and magnitude of the control arm deflection varied somewhat. The pitch-control system of the model provided a fore-and-aft movement of the center of gravity of about ± 0.03 of the keel length; the roll-control system provided a lateral shift of the center of gravity of about ± 0.045 of the keel length.

Instrumentation

A 16-millimeter electrically driven motion-picture camera with a 17-millimeter wide-angle lens was mounted in the front of the booster for most

of the tests. The camera was positioned so as to photograph a flow-direction vane attached to a nose boom on the booster (fig. 2) and also to photograph control-position indicators and a timing light mounted on a panel inside the booster; the flow-direction vane indicated the angles of attack and sideslip at the end of the nose boom of the booster. The camera also recorded the view of the horizon and surrounding terrain to facilitate the qualitative evaluation of the motions of the model.

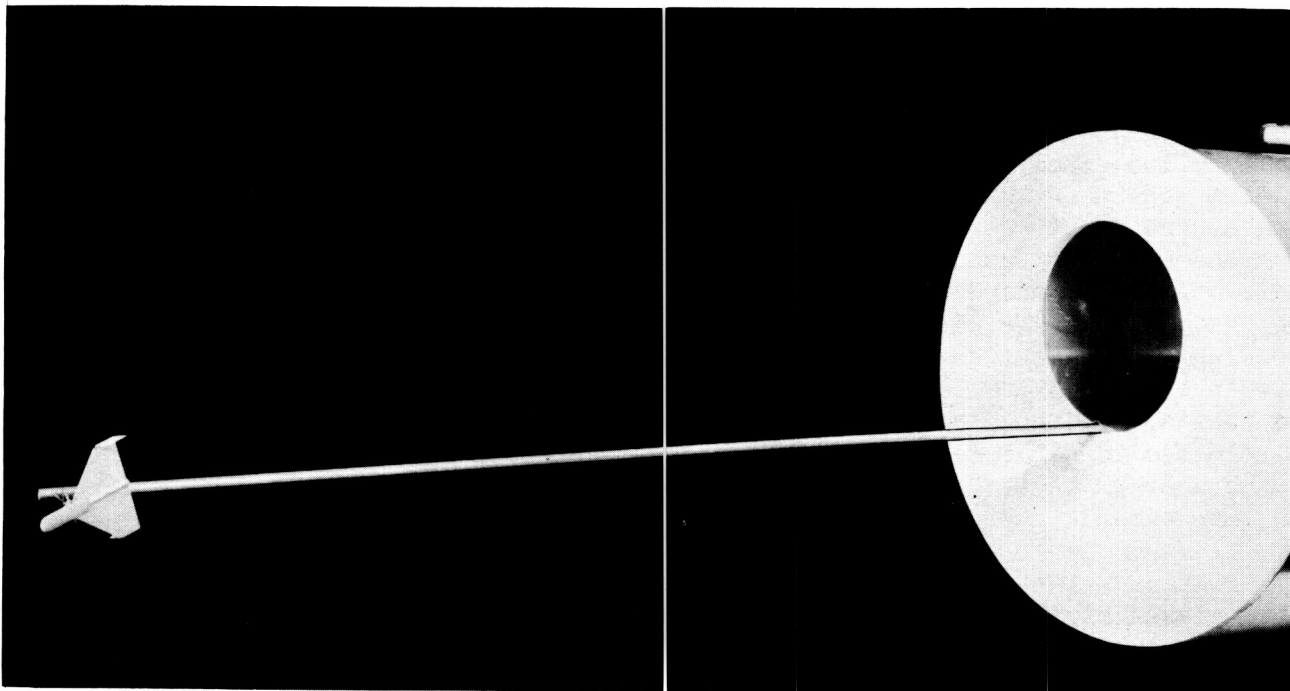


Figure 2.- Photograph of flow-direction vane which indicates angles of attack and sideslip. L-63-127

The angles of attack and sideslip were measured at the nose boom for convenience although it was desired to determine these angles at the wing keel. The nose boom was 44 inches long (model scale) and the distance from the center of gravity of the booster-parawing combination to the flow-direction vane was 87.5 inches (model scale). Because during the flights the angular rates were fairly small, the values at the nose boom were considered to be indicative of those at the wing keel with the provision that the angle of attack of the wing keel is approximately equal to the angle of attack measured at the nose boom plus the included angle (16°) between the booster and wing keel.

MODEL TEST TECHNIQUES, TEST FACILITIES, AND EQUIPMENT

Free-Flight Tests

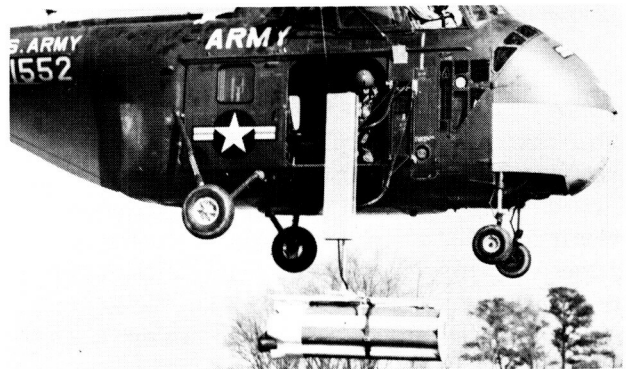
The model flight-test technique consists primarily of launching, from a helicopter either in forward or hovering flight, unpowered dynamically scaled



Figure 3.- Photograph of ground stations showing the roll-yaw pilot and pitch pilot in position. L-60-1879



(a) Model raised. L-62-400



(b) Model lowered. L-62-401

Figure 4.- Photograph of model on launch rig in raised and lowered position.

radio-controlled models, and of controlling the flights from the ground. Evaluation of the flight behavior is based on the model pilots' observations and the quantitative measurements obtained from motion-picture records.

The flight tests were performed at an isolated area near Langley Air Force Base, Virginia. The radio-control and tracking equipment used in the present investigation were somewhat similar to those described in reference 6. In brief, two ground stations were used for controlling the model, one for the pilot who operated the pitch controls and one for the pilot who operated the roll controls (see fig. 3). Each ground station was provided with a radio-control transmitter, communications equipment, motorized tracking unit equipped with a telephoto motion-picture camera, and binoculars to assist the pilots and trackers in viewing the flights of the model. All phases of the operation were directed by a coordinator located near the ground stations. Magnetic tape recorders were used to record control signals and all voice communications between the helicopter, coordinator, and model pilots in order to assist in analysis of results.

A helicopter equipped with a special launching rig was used to launch the models for the deployment tests. This rig was mounted on the side of the helicopter near the door (see fig. 4(a)) and was raised and lowered by a hydraulic hoist. When the model was ready to be launched, the rig was lowered so that the model was below the helicopter. (See fig. 4(b).) For the stability and control tests, an alternate launch rig system was used which consisted of launching the model in forward flight with the parawing already deployed from the end of a 300-foot steel cable, the other end of which was attached to the helicopter. (See fig. 5.)

Since several sizes of parachutes (flat circular type) were utilized during the investigation, their uses will be described briefly. The dimensions of the parachutes are model scale. For the stability and control tests, a 3-foot-diameter parachute was attached to the end of the booster to stabilize the booster

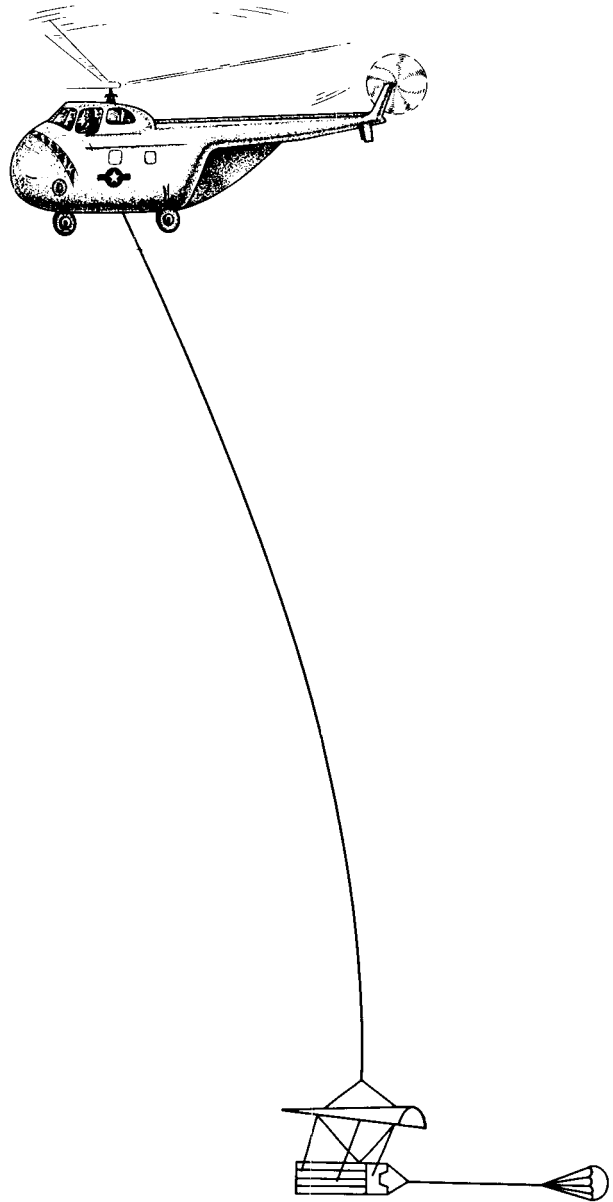


Figure 5.- Sketch of alternate launch rig system for model.

with the parawing deployed while the combination was in towed flight; this procedure was necessary since even with the parawing lifting, the combination was directionally unstable while being towed. During the deployment tests a 5-foot-diameter parachute was required to stabilize the booster before the parawing was deployed. The risers for both sizes of parachutes were 6.3 feet in length and were restrained on the booster at three equally spaced attachment points by using a bridle. The parachute was jettisoned in response to a radio control signal. A smaller 2-foot-diameter parachute was used as a drogue to pull and hold the parawing away from the booster during the deployment process. The small drogue was connected to the end of a short mast which in turn was attached to the top of the parawing. (See fig. 6.) This mast was fitted in a slotted hinge where it

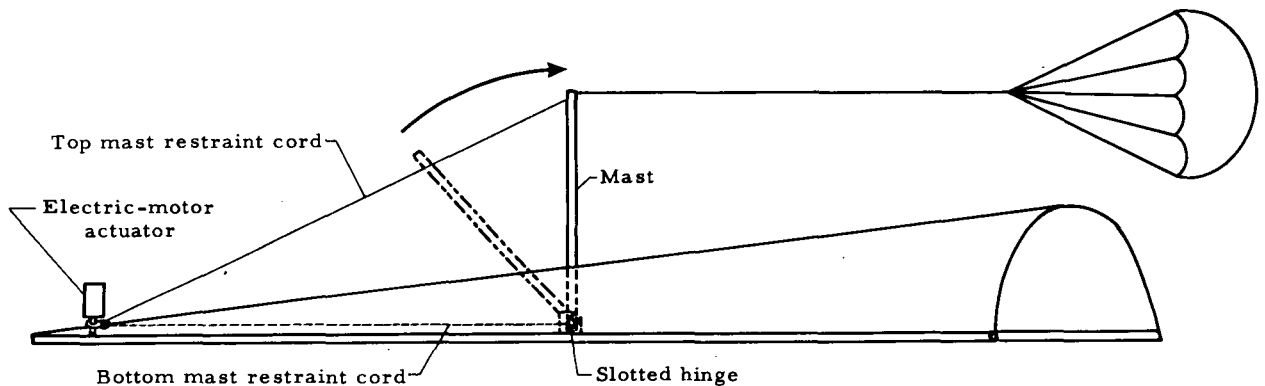


Figure 6.- Sketch of model showing action of drogue parachute used in pulling and holding parawing away from booster.

was attached to the parawing so the mast could be folded forward and parallel to the keel when the parawing was stowed. Two nylon cords, one connected to the top and one to the bottom of the mast, were run forward and connected to a small electric-motor actuator on top of the parawing. When the small drogue was deployed, it pulled the mast erect, the nylon cords preventing the mast from going past the vertical. In response to a radio signal the electric motor jettisoned the cords, mast, and parachute.

The model normally was retrieved by gliding it to a landing; however, a 12-foot-diameter parachute was available for emergency purposes. The parachute was packed in a metal can which was attached to the tail of the booster. The lid of the can was released by radio control and a pilot parachute was ejected by a spring into the free airstream and thus the main parachute was extracted quickly and positively.

Wind-Tunnel Tests

The wind-tunnel tests were conducted in the Langley 20-foot free-spinning tunnel (ref. 7) which is an atmospheric wind tunnel with a vertically rising airstream in the test section; the maximum airspeed of the tunnel is approximately 98 feet per second. In order to conduct the deployment tests in the wind

tunnel, the booster was suspended from the tail end by a rope which in turn was attached to another rope which spanned the middle of the tunnel. (See fig. 7.) Two additional hand-held lines were attached to the nose of the booster to provide lateral restraint. This arrangement allowed the booster some freedom in pitch. Each step on the deployment sequence was initiated by radio control commands. Evaluation of the tests was based on visual observation and motion-picture records.

TESTS

Wind-Tunnel Tests

As previously mentioned, in order to keep the free-flight tests to a minimum, preliminary deployment tests were conducted on the model suspended in the Langley 20-foot free-spinning tunnel prior to the free-flight tests. The tests were conducted at tunnel speeds up to 70 feet per second. In order to isolate the deployment problems and be able to correct them one at a time, the deployment sequence was performed in stages. The first stage consisted of positioning the parawing and its lines on the booster with the parawing retracted laterally and already unfolded longitudinally (extended to its full length). When a satisfactory deployment was obtained from this stage, the next and final stage was started which consisted of stowing the parawing on the booster with the wing retracted laterally and folded longitudinally and repeating the deployment process.

Free-Flight Tests

Free-flight stability and control tests were performed to determine the proper trimmed flight condition of the model so that, when subsequent deployment tests were made, any unusual motion occurring during the deployment and accompanying transition from vertical descent to normal trimmed gliding flight could be attributed directly to the deployment process and not to any untrimmed condition of the model.

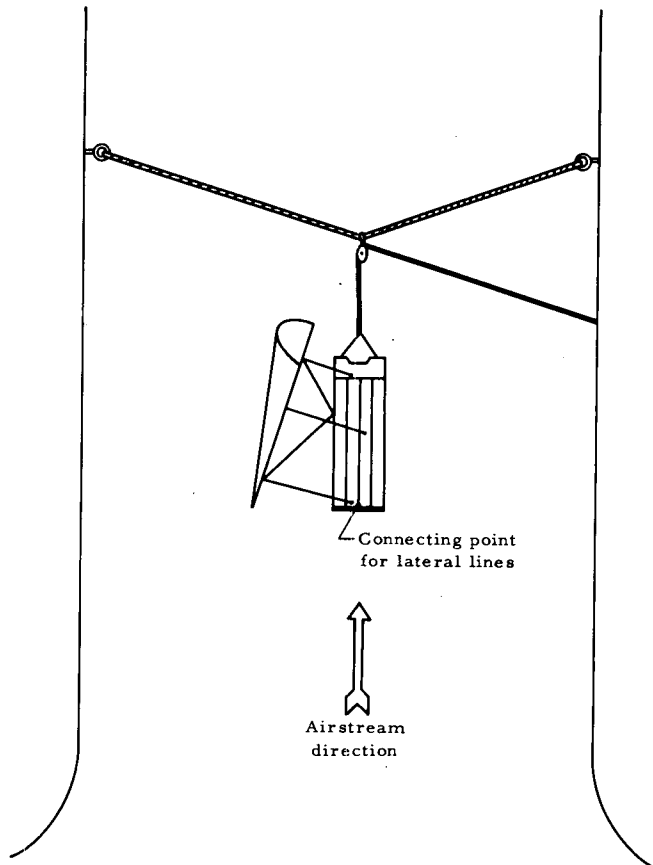
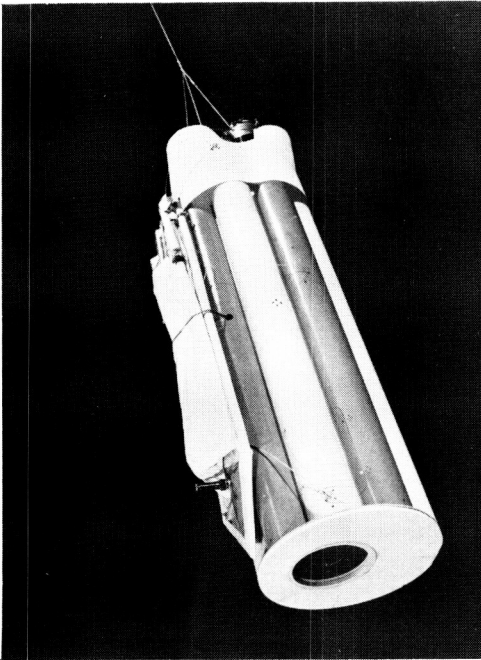
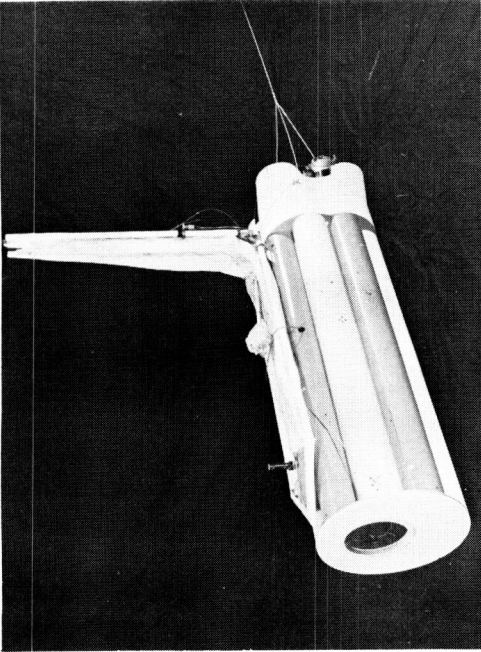


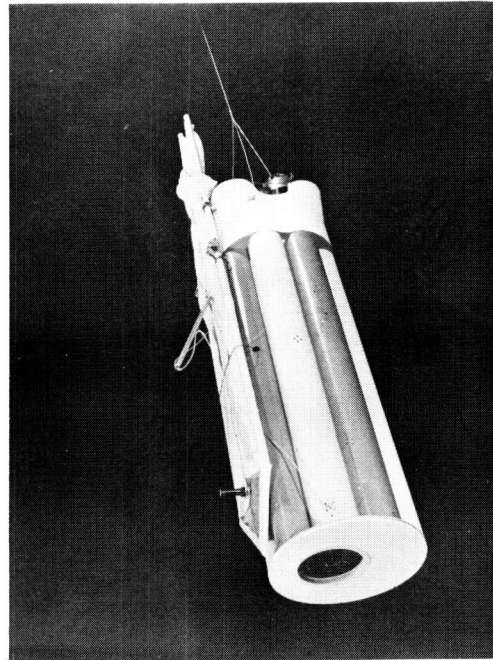
Figure 7.- Sketch of model showing booster suspended in Langley 20-foot free-spinning tunnel. Lateral hand lines connected to nose of booster not shown.



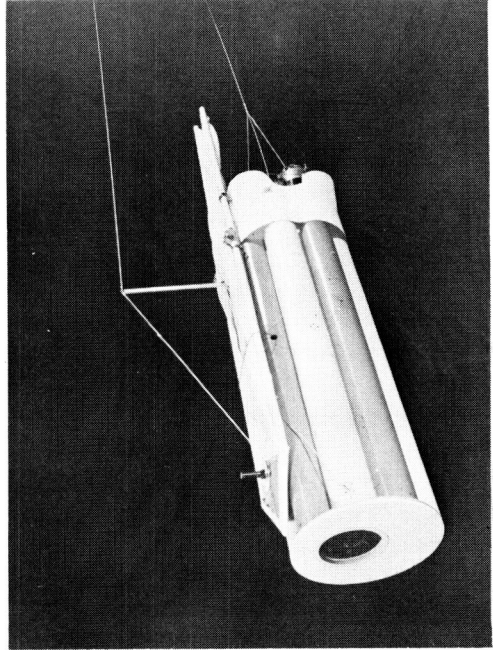
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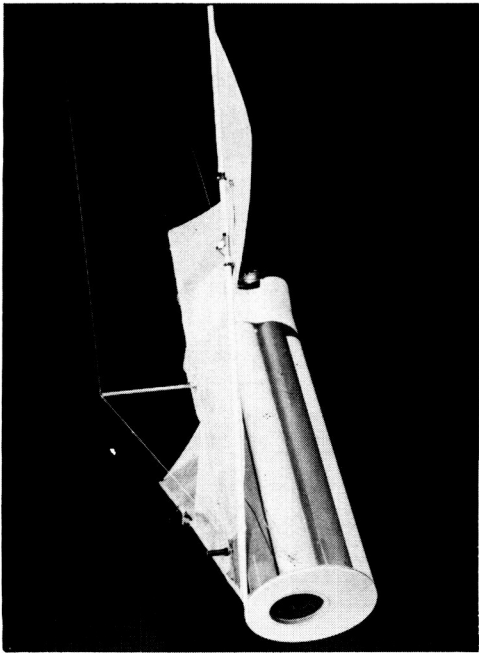


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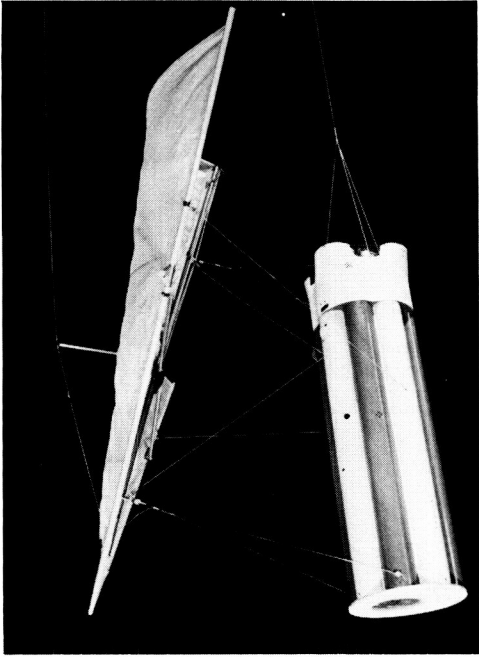


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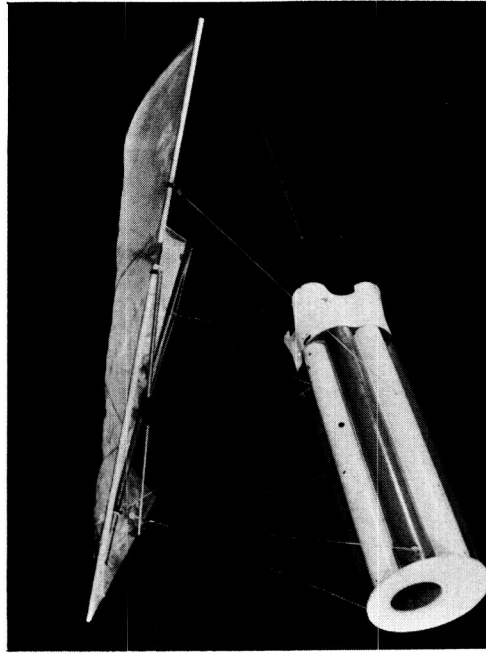
Figure 8.- Deployment sequence of booster-parawing combination. Numbers indicate sequence. L-63-3116



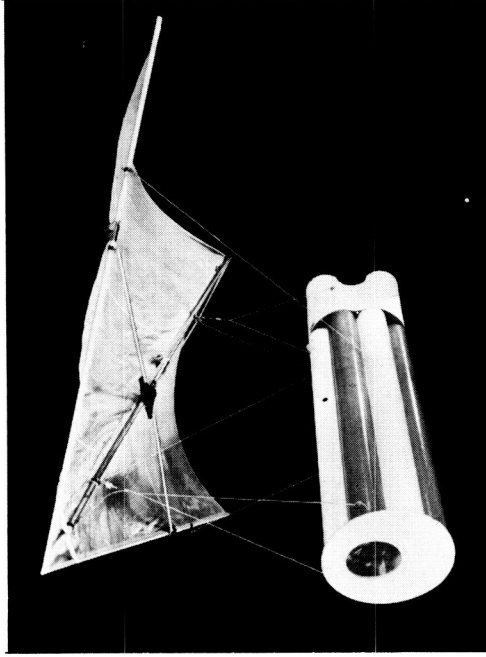
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Figure 8.- Concluded.

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Stability and control tests.- For the stability and control tests, the model was trimmed at an angle of attack as close as possible to the maximum lift-drag ratio and launched in forward flight from the helicopter at an airspeed of about 20 knots and an altitude of about 2,000 feet. The flight tests consisted of a series of glides in which both longitudinal and lateral controls were operated to fly the model through desired maneuvers. When possible, attempts were made to glide the model to a landing.

Deployment tests.- For the deployment tests the model was released from the helicopter near zero airspeed and at an altitude of about 3,500 feet, and a satisfactory deployment sequence of the parawing was determined.

RESULTS AND DISCUSSION

A motion-picture film supplement to this paper showing motion-picture records of some of the flights has been prepared and is available on loan. A request card form and a description of the film will be found at the back of this paper, on the page immediately preceding the abstract and index page.

Typical results obtained in the investigation are presented in terms of time histories of the motion in terms of a corresponding full-scale vehicle. Unless otherwise noted, all the results will be based on tests of the model with the center of gravity at the normal location.

The wind-tunnel and free-flight deployment tests were performed to determine the proper deployment sequence for consistent transitions from descent flight with the parawing stowed on the booster to normal trimmed gliding flight with the parawing deployed. During the course of the deployment tests, various problem areas were encountered and resolved. A photograph showing a typical deployment sequence is shown in figure 8.

Stability and Control Characteristics

In general, the flight characteristics of the model were fairly satisfactory for an unmanned vehicle although the model had a small constant-amplitude Dutch roll oscillation and some undesirable characteristics at the stall. Unless proper precaution was exercised, the booster-parawing combination could be stalled abruptly which would lead to the combination pitching down and tumbling and thus cause the booster to fall on top of the parawing. The model was controllable by center-of-gravity movement but the response of the model appeared to be sluggish for the range of control inputs used.

The steady-glide characteristics of the model with no control inputs are shown in figure 9. The first portion of the flight ($t = 0$ to 56 seconds full scale) shows the stability characteristics of the model with the small drogue parachute (3-foot-diameter) attached to the end of the booster. The model was slightly out of trim laterally and was turning slowly to the right. The angles of attack and sideslip varied somewhat but averaged about 21° and 3° ,

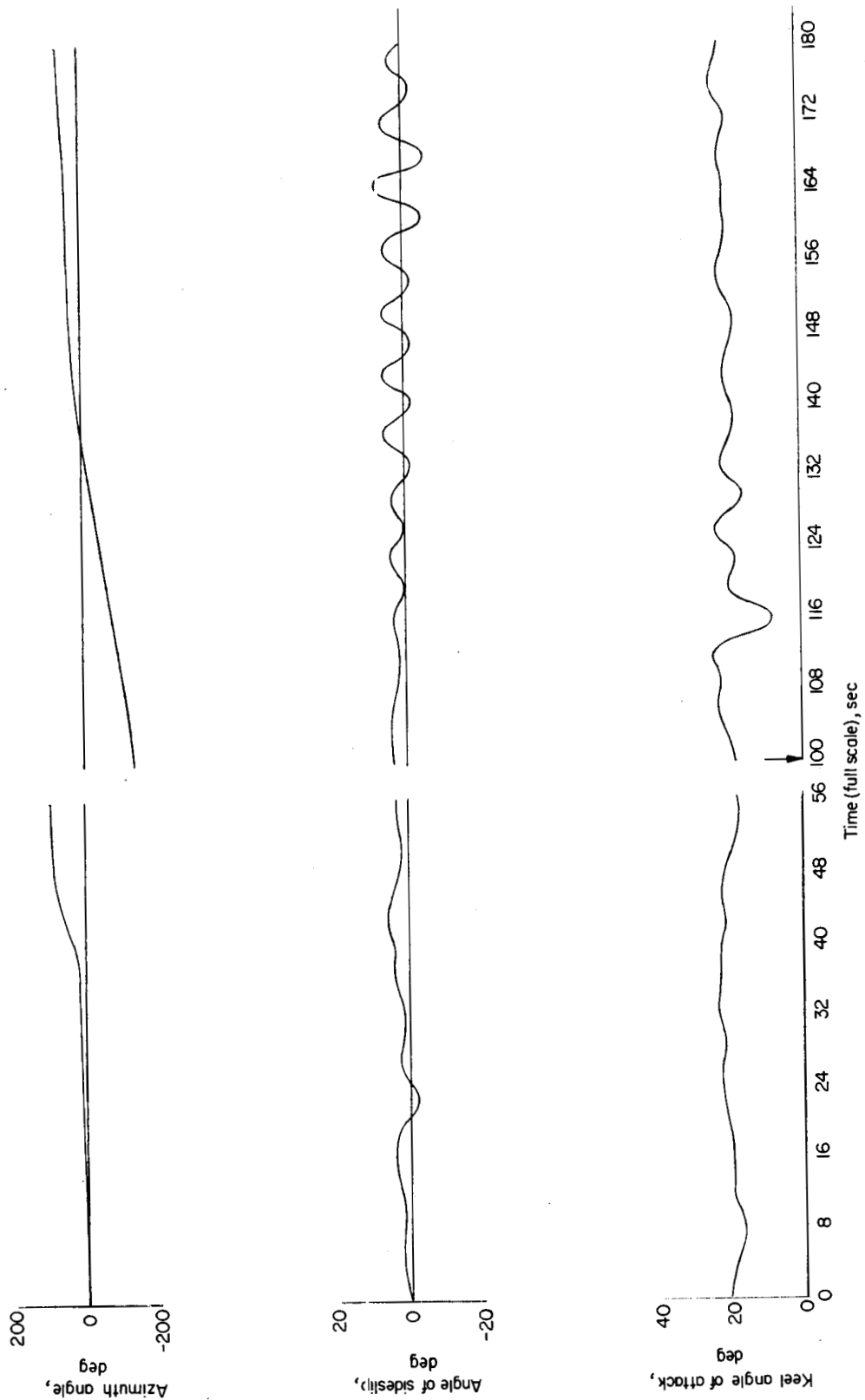


Figure 9.- Time history of steady glide characteristics of model with no control inputs. Time at which drogue parachute was jettisoned is indicated by vertical arrow in time scale.

respectively. When the parachute was jettisoned, the lateral stability characteristics of the model changed somewhat and a Dutch roll oscillation was evidenced by the variation of the sideslip angle; the period of the oscillation was 7 seconds, full scale. The angle of attack, which did not appear to be affected appreciably by the Dutch roll oscillation, remained at about 21° .

As previously mentioned, a few tests were performed with the center of gravity of the booster-parawing combination located slightly aft of the normal center-of-gravity location. The results of these tests essentially were similar to the results obtained when the center of gravity was at its normal location with the exception that the model flew at a higher trim angle of attack and appeared to be close to the stall. Because in this flight condition the amplitude of the Dutch roll oscillation was increased and the pitch control was too sensitive, only a few flights were made for this center-of-gravity location.

Deployment Characteristics

Wind-tunnel tests.- As mentioned previously, preliminary wind-tunnel deployment tests were conducted in order to keep the free-flight tests to a minimum. These wind-tunnel tests revealed certain problem areas that needed to be resolved. For example, the results showed that prior to deployment of the parawing, the suspension, roll-control, and pitch-control lines had to be positioned and secured to the booster properly so as to prevent entangling either the parawing or booster in the lines when a deployment was attempted. With the parawing folded longitudinally, a tunneling effect in the fabric near the nose of the parawing was noted when exposed to the airstream. This effect caused the fabric to billow out. This problem was solved by covering the parawing, in the stowed position, with heavy paper which shielded the wing against the airstream; the paper was thrown free when the wing unfolded longitudinally. After the wing was unfolded longitudinally, the fabric material near the trailing edge of the parawing tended to billow out somewhat and whip around in the airstream but did not become entangled on the booster for any of the tests.

The tunnel tests indicated that use of a small drogue parachute to pull the parawing clear of the booster and into a flying condition and then jettisoning the parachute would be satisfactory. It was noted, in some instances, that, if the parawing started developing much lift before the spreader bar locked into position, the spreader bar would never lock into place. Based on this result the tension in the shock cord was increased until the wing deployed properly.

In general, wind-tunnel results showed that, if certain predetermined procedures were adhered to in stowing and deploying the parawing, reliable deployments could be obtained. The results also indicated that on the full-scale vehicle, it would be desirable to have the suspension lines attached to reels on the booster which could take up slack in the lines or play it out as needed and thus keep tension in the lines at all times. This procedure would help prevent the parawing or booster from becoming entangled in the suspension lines during the deployment process. Also reeling out the lines slowly would prevent large shock loads.

Free-flight tests.- The initial free-flight tests were conducted with the parawing stowed on the booster in the unfolded position in order to simplify the deployment process. In order to avoid possible pitch-up into the stall, the small drogue parachute which was attached to a 3-foot mast was to be automatically jettisoned after the parawing deployed and the suspension lines became taut. The large drogue parachute, which was to remain attached to the booster during the deployment process and until gliding flight had been obtained, would then be jettisoned.

In all cases, when the parawing was released for deployment, the parawing separated from the booster and developed fairly well, the fabric would then luff, and the wing would crash back into the booster. The process would repeat until the large drogue parachute which stabilized the booster was jettisoned. It is believed that the to-and-fro motions of the parawing on the booster when it was first deployed were caused by the parawing angle of attack varying such that the parawing sometimes was in a region of low angles of attack where the fabric would luff and other times the angle of attack momentarily would be sufficiently high so that the parawing was developing lift properly. During this process the suspension lines sometimes would become entangled on the booster or parawing and thus, in some instances, would cause the wing to become skewed relative to the booster. When the large parachute was jettisoned and the model attempted to attain a gliding flight attitude, it would enter a series of violent gyrations.

On the basis of the preceding results, it was therefore decided to retain the small parachute longer and to release it by radio control. This arrangement allowed the small parachute to hold the wing away from the booster a sufficient length of time so that even though the wing was not producing as much lift as desired it still was sufficient to pull the booster from an approximate vertical-descent condition to a steep inclined glide path; thus the parawing would have an angle of attack high enough that the canopy would remain developed when the small parachute was jettisoned. At first it was decided to release the large parachute before the small parachute so as to assure that the model would remain in gliding flight during transition and not possibly return to a vertical-descent condition because of the drag of the large parachute if it was jettisoned last. However, when the large parachute was jettisoned first, the model quickly developed a large pitching oscillation which was divergent and caused the model to partially stall. Only by quickly jettisoning the small parachute was the pilot able to prevent the model from completely stalling. In an effort to reduce the nose-up pitching moment of the model to prevent this stalling condition the mast on the parawing was shortened from 3 feet to 1/2 foot, but this shortening of the mast still did not prevent the model from stalling when the large parachute was jettisoned before the small one. Therefore, in order to prevent this stalling tendency of the model, it was decided to jettison the small parachute first and the large parachute last.

At this stage in the test program it also was decided to proceed with the final or full deployment sequence by folding the parawing longitudinally and stowing it completely within the length of the booster. The results of the flight tests using this deployment sequence were satisfactory. In brief, the flight tests consisted of allowing the booster to descend vertically with the large drogue parachute already deployed for stabilization purposes. The wing

was then unfolded longitudinally and simultaneously the second smaller drogue parachute was deployed. After this sequence the wing was freed from the side of the booster and allowed to spread laterally. The small parachute then pulled the wing away from the side of the booster and held it away satisfactorily. The small parachute was jettisoned first, and the flight angle of the model appeared to steepen slightly, but no tendency was observed for the parawing canopy to collapse. Also, no apparent oscillations in roll or pitch developed. Finally, when the large parachute was jettisoned, the model attained a normal trimmed flying attitude.

During the course of testing, another problem area was encountered which involved the tangling of the small parachute on the riser of the large parachute and thus, prevented the jettisoning of the large parachute. In order to avoid this condition, the riser length of the small parachute was reduced. The new length of the riser was chosen so that it was short enough to prevent the small parachute from reaching the riser of the large parachute and yet long enough so that the small parachute would not be affected too much by the wake of the wing. Brief tests in a wind tunnel with the new riser length indicated that the small parachute would not collapse although it oscillated slightly; subsequent free-flight tests substantiated these wind-tunnel tests.

SUMMARY OF RESULTS

The following conclusions are based on the results of a free-flight investigation to determine the deployment, dynamic stability, and control characteristics of a parawing having rigid members used as a recovery device for a model of a large booster:

1. A satisfactory deployment technique has been developed which provides consistent transitions from vertical descent flight at subsonic speeds with the parawing stowed on a drogue-parachute-stabilized booster to normal trimmed gliding flight with the parawing deployed.
2. For the particular deployment configuration selected, a small drogue parachute was needed to hold the parawing away from the booster during deployment until the parawing was developing lift properly.
3. For the sweep angle selected for this parawing configuration, some positive means (such as a spreader bar) was required for extending the parawing laterally and locking it.
4. In general, the flight characteristics of the model were fairly satisfactory for an unmanned vehicle although the model had a small constant-amplitude

Dutch roll oscillation and some undesirable characteristics at the stall. The model was controllable by center-of-gravity movement but the response of the model appeared to be sluggish.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., May 1, 1963.

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